HUMIDITY EFFECT ON PAPER FLATNESS
USING 3D PROFILOMETRY

Prepared by
Duanjie Li, PhD

6 Morgan, Ste156, Irvine CA 92618 · P: 949.461.9292 · F: 949.461.9232 · nanovea.com

INTRODUCTION

Humidity, the amount of water vapor in the air, plays an important role in the performance of instruments in different industries. For example, high humidity may cause malfunction of electronic devices. The condensation on the circuit boards results in short circuit inside the instrument. High humidity also reduces the capacity of chemical plants and refineries where furnaces are used in the process. Humidity control is critical in the paper and pulp industry. Composed of cellulose fibers, paper is hygroscopic in nature. It absorbs moisture from a humid atmosphere, leading to changes in paper dimensions, flatness and strength.

IMPORTANCE OF 3D PROFILOMETRY IN HUMIDITY

Flatness is critical to the proper performance of printing paper. It communicates functional characteristics and makes an impression of the paper quality. A better understanding of the effect of humidity on paper flatness, texture and consistency allows optimizing the processing and control measures to obtain the best product. Quantifiable, precise and reliable surface inspection of the paper in different humid environments is in need to simulate the use of paper in the realistic application. The Nanovea 3D Non-Contact Profilometers utilizes chromatic confocal technology with unique capability to precisely measure the paper surface. A humidity controller provides precise control of the humidity in a sealed chamber where the test sample is exposed to the moisture.

MEASUREMENT OBJECTIVE

In this study, the Nanovea ST400 non-contact profilometer equipped with a humidity chamber and a humidity controller is used to measure the surface morphology of a commercially available printing paper exposed to atmosphere of different humidity. We showcase the capacity of Nanovea non-contact profilometer in providing precise 3D profile measurement of samples in a humid environment.

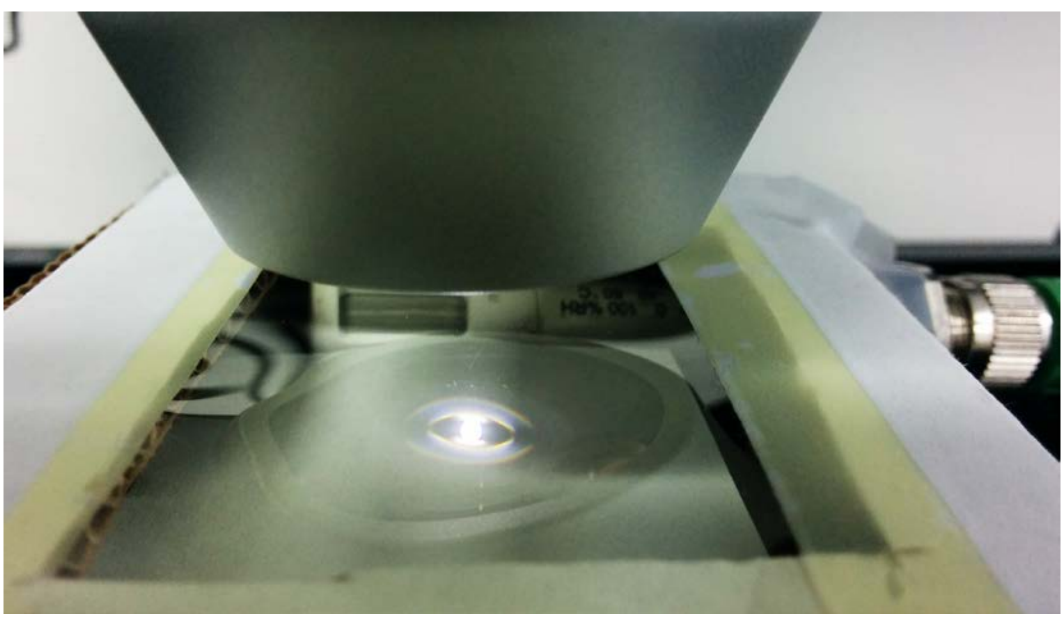


Fig. 1: Optical line sensor scanning on the paper in the humidity chamber.

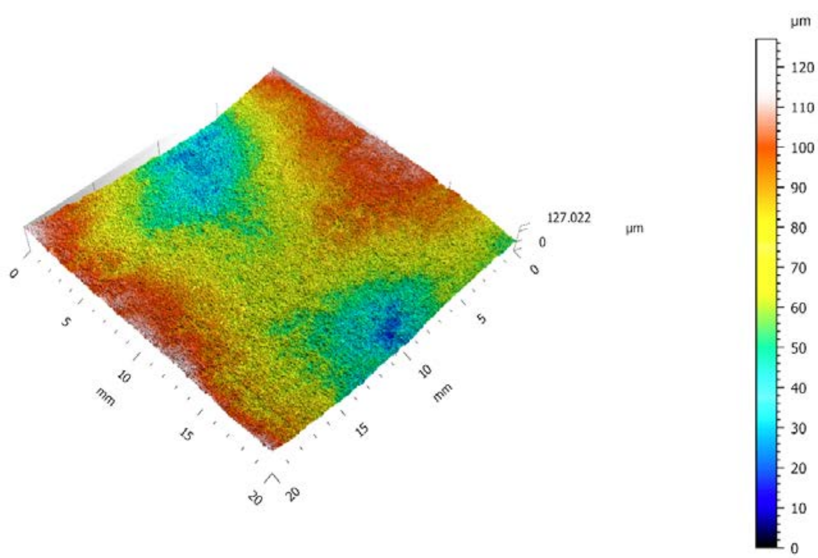
RESULTS AND DISCUSSION

The printing paper was cut and placed in the humidity chamber, with the relative humidity (RH) value controlled by a humidity controller attached to the chamber. The 3D surface morphology of the paper was first measured in an atmosphere with a RH value of 50%, which is close to that of the ambient atmosphere. The RH value in the chamber was then raised to 90%, and the printing paper was kept in such environment for 2 h. A 20-second 3D surface measurement at this 90% RH was performed. The moisture was discharged and the humidity chamber maintains a RH value at 10 % for another 2 h, followed by the last 3D surface measurement of the paper.

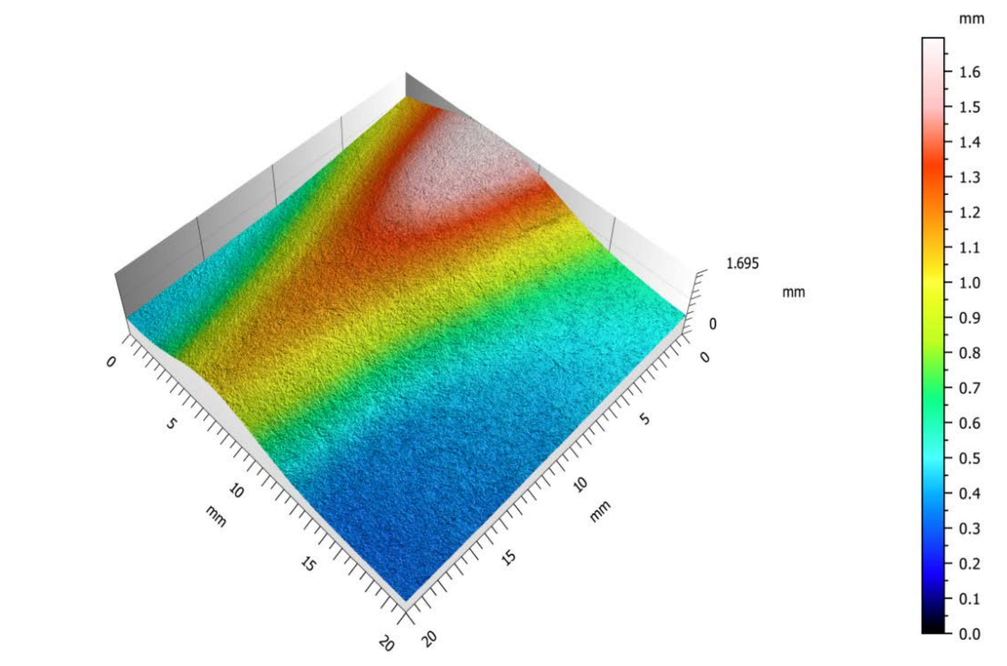
The 3D view and the false color view of the printing paper at different humidity are shown and compared in Fig. 2 and Fig. 3, respectively. The Flatness and Roughness values of the paper at different humidity are listed in Table 1. The flatness value was directly calculated from the 3D surface profile as measured, and the roughness value was obtained after the form removal was performed in the analysis software. It can be observed that the printing paper is relatively flat before its exposure to excessive humidity. The FLTq value is 19.3 µm. As the RH value increases to 90%, the high level of moisture causes swelling and distortion of the paper, leading to formation of a ridge at the center and significantly increased FLTq value of 375 µm. When the moisture in the paper is removed by being exposed to the atmosphere with a RH value of 10%, the FLTq value reduces to 55.3 µm.

The humidity changes the dimension of individual cellulose fibers in the paper. A high moisture content in paper increases the paper dimension. The variation in the environmental moisture content and the directional cellulose fiber alignment results in change of paper flatness. Depending on the percentage of fibers present in the paper and the degree of bonding within the paper structure, papers react to the humidity change in different ways. Nanovea non-contact profilometer equipped with a humidity chamber and a humidity controller provides an ideal tool to precisely measure the 3D profile of paper samples in a humid environment.

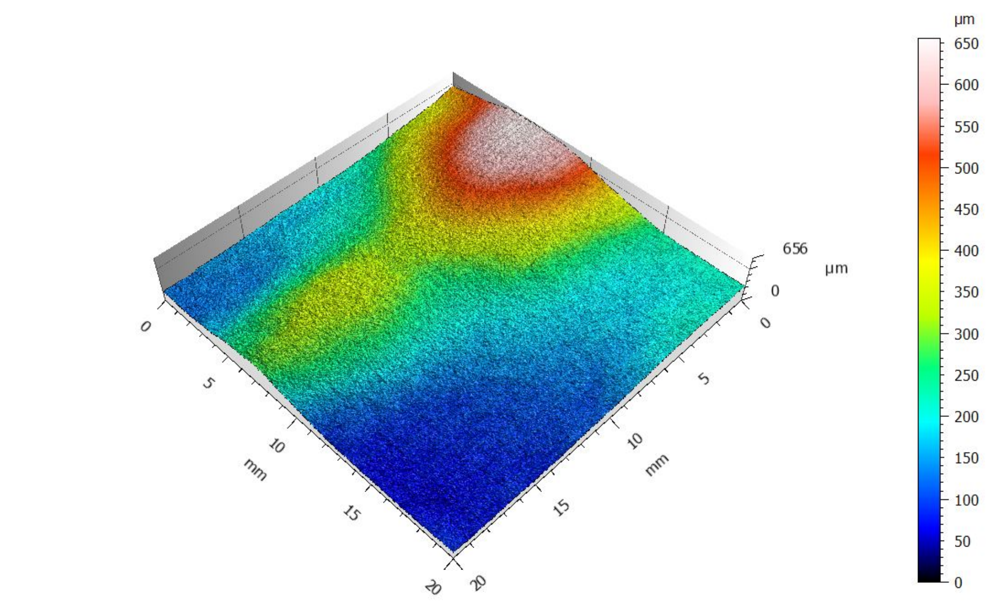
(a) 50 % RH:



(b) 90% RH:


mm
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
1.695
mm
0
0
5
10
mm
15
20
0
5
10
mm
15
20

(c) 10% RH:


µm
650
600
550
500
450
400
350
300
250
200
150
100
50
0
656
µm
0
0
5
10
mm
15
20
0
5
10
mm
15
20

(d) 3D morphology change in the same scale:

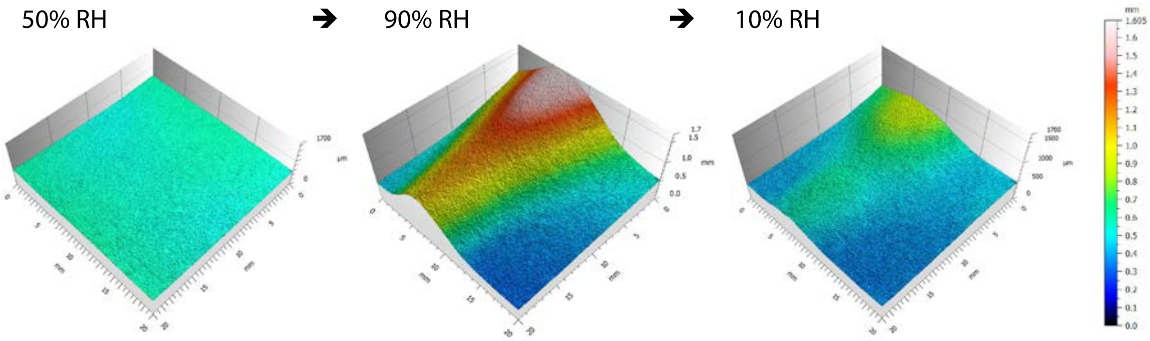
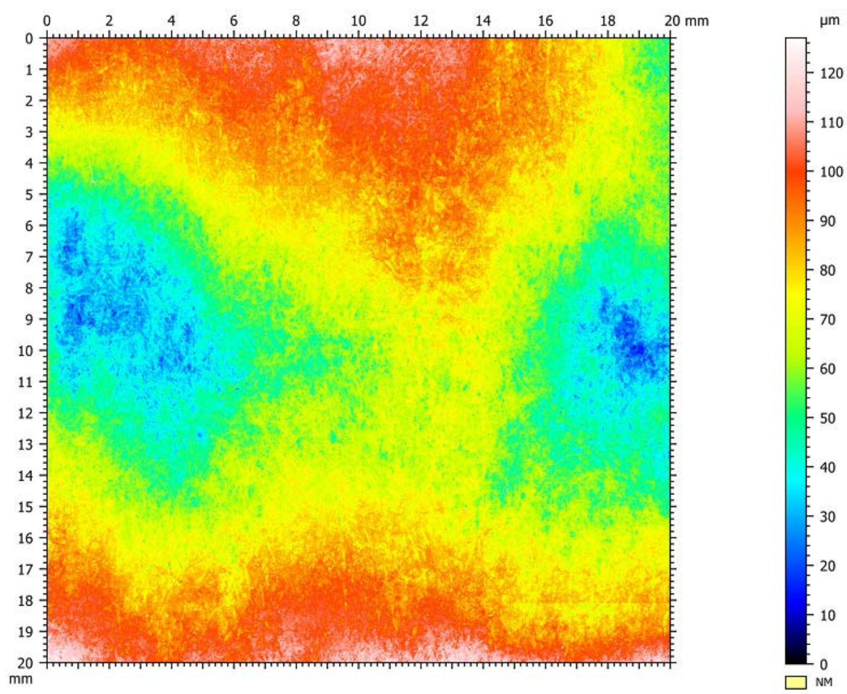
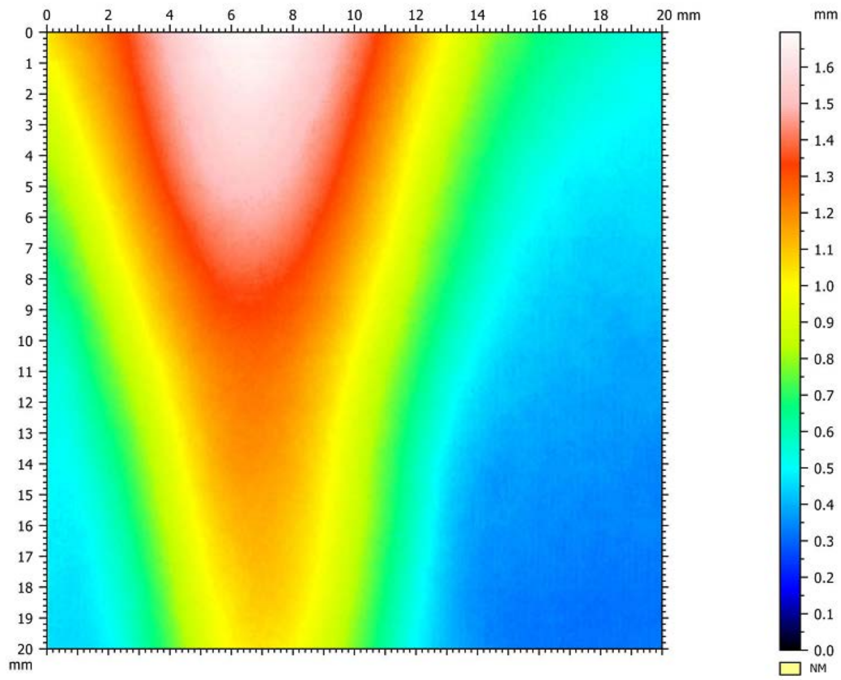


Fig. 2: 3D view of the printing paper at different humidities.

(a) 50 % RH:



(b) 90% RH:



(c) 10% RH:

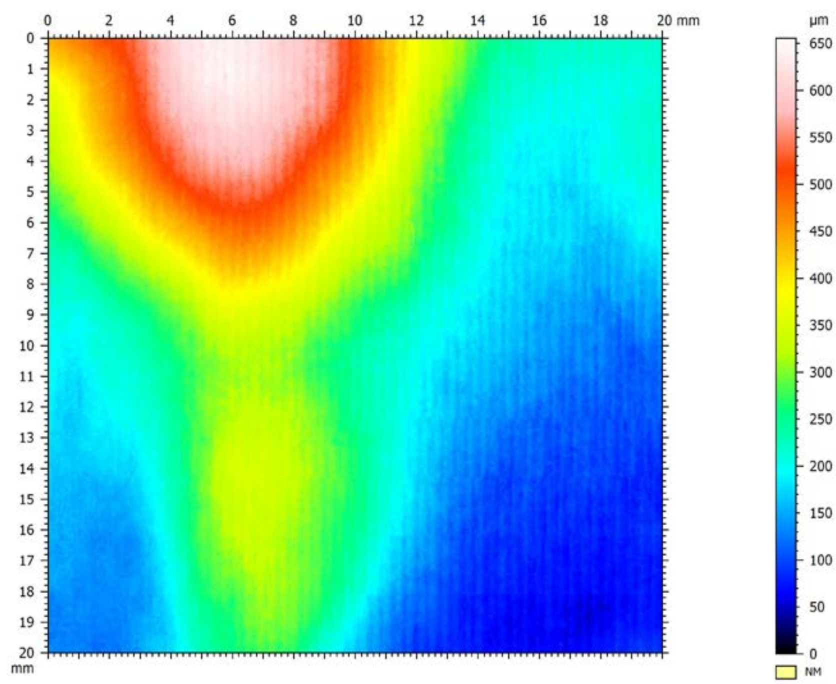


Fig. 3: False color view of the printing paper at different humidities

Name	Unit	50% RH	90% RH	10% RH	
Flatness Values by ISO 12781					
FLTt	µm	95.1	1352.4	127.0	Peak-to-valley flatness deviation of the surface
FLTp	µm	45.0	826.8	70.0	Peak-to-reference flatness deviation
FLTv	µm	50.2	525.6	57.0	Reference-to-valley flatness deviation
FLTq	µm	19.3	375.0	55.3	Root-mean-square flatness deviation
Roughness Values by ISO 25178					
Sq	µm	5.73	14.4	13.8	Root-mean-square height
Sp	µm	72.9	199	122	Maximum peak height
Sv	µm	552	597	358	Maximum pit height
Sz	µm	625	796	480	Maximum height
Sa	µm	4.51	10.9	11.2	Arithmetic mean height

Table 1: Flatness and Roughness values of the printing paper at different humidity.

CONCLUSION

In this application, we have showcased that the Nanovea ST400 3D Non-Contact Profilometer equipped with a line sensor and a humidity chamber is an ideal tool for analyzing the surface morphology of samples exposed to a humid environment.

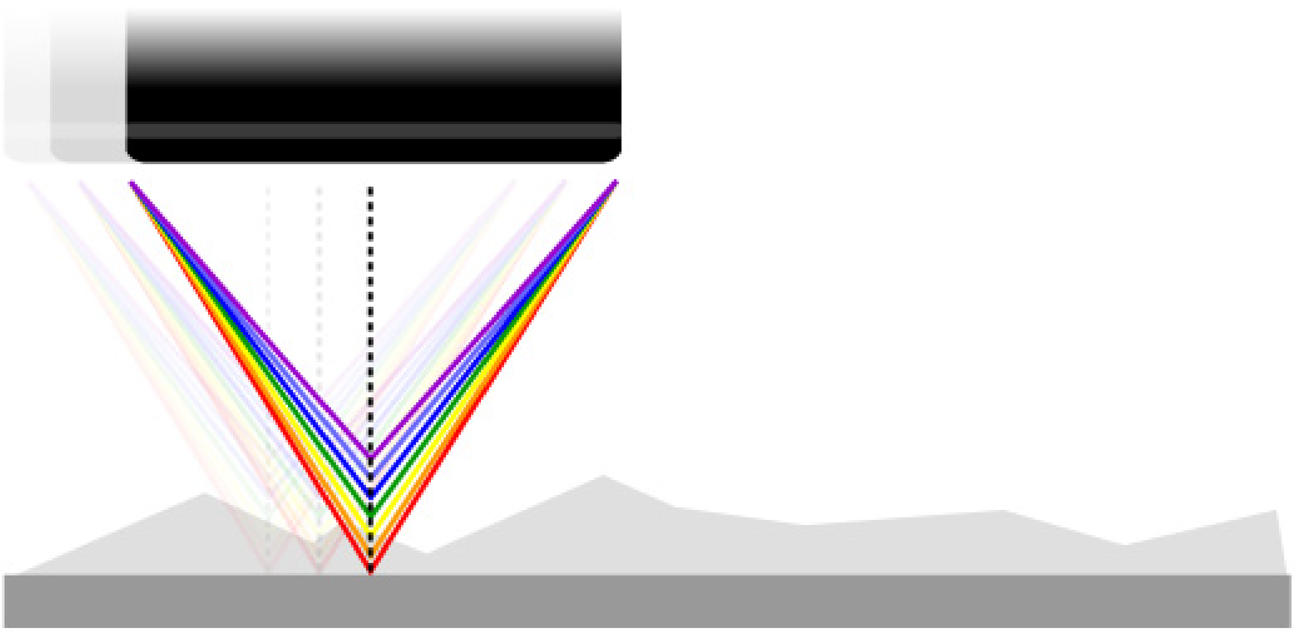
The moisture content in air plays an important role in the flatness of the printing paper. Undesirable appearance and quality defects like buckles occur when the papers are exposed to the environment with a varied humidity. In this study, the paper significantly distorted as the relative humidity value increases from 50% to 90%. Such a distortion is reduced when the paper is exposed to a dry environment of RH value 10%, as the moisture content in the paper is discharged.

The data shown here represents only a portion of the calculations available in the analysis software. Nanovea Profilometers measure virtually any surface in fields including Semiconductor, Microelectronics, Solar, Fiber Optics, Automotive, Aerospace, Metallurgy, Machining, Coatings, Pharmaceutical, Biomedical, Environmental and many others.

Learn more about the Nanovea Profilometer or Lab Services

MEASUREMENT PRINCIPLE:

The Chromatic Confocal technique uses a white light source, where light passes through an objective lens with a high degree of chromatic aberration. The refractive index of the objective lens will vary in relation to the wavelength of the light. In effect, each separate wavelength of the incident white light will re-focus at a different distance from the lens (different height). When the measured sample is within the range of possible heights, a single monochromatic point will be focalized to form the image. Due to the confocal configuration of the system, only the focused wavelength will pass through the spatial filter with high efficiency, thus causing all other wavelengths to be out of focus. The spectral analysis is done using a diffraction grating. This technique deviates each wavelength at a different position, intercepting a line of CCD, which in turn indicates the position of the maximum intensity and allows direct correspondence to the Z height position.



Unlike the errors caused by probe contact or the manipulative Interferometry technique, Chromatic Confocal technology measures height directly from the detection of the wavelength that hits the surface of the sample in focus. It is a direct measurement with no mathematical software manipulation. This provides unmatched accuracy on the surface measured because a data point is either measured accurately without software interpretation or not at all. The software completes the unmeasured point but the user is fully aware of it and can have confidence that there are no hidden artifacts created by software guessing.

Nanovea optical pens have zero influence from sample reflectivity or absorption. Variations require no sample preparation and have advanced ability to measure high surface angles. Capable of large Z measurement ranges. Measure any material: transparent or opaque, specular or diffusive, polished or rough. Measurement includes: Profile Dimension, Roughness Finish Texture, Shape Form Topography, Flatness Warpage Planarity, Volume Area, Step-Height Depth Thickness and many others.

DEFINITION OF HEIGHT PARAMETERS

	Height Parameter	Definition
Sa	Arithmetical Mean Height	Mean surface roughness. $$Sa = \frac{1}{A}\iint_A \lvert z(x,y)\rvert dxdy$$
Sq	Root Mean Square Height	Standard deviation of the height distribution, or RMS surface roughness. $$Sq = \sqrt{\frac{1}{A}\iint_A z^2(x,y)dxdy}$$ Computes the standard deviation for the amplitudes of the surface (RMS).
Sp	Maximum Peak Height	Height between the highest peak and the mean plane.
Sv	Maximum Pit Height	Depth between the mean plane and the deepest valley.
Sz	Maximum Height	Height between the highest peak and the deepest valley.
Ssk	Skewness	Skewness of the height distribution. $$Ssk = \frac{1}{Sq^3}\left[\frac{1}{A}\iint_A z^3(x,y)dxdy\right]$$ Skewness qualifies the symmetry of the height distribution. A negative Ssk indicates that the surface is composed of mainly one plateau and deep and fine valleys. In this case, the distribution is sloping to the top. A positive Ssk indicates a surface with a lot of peaks on a plane. Therefore, the distribution is sloping to the bottom. Due to the large exponent used, this parameter is very sensitive to the sampling and noise of the measurement.
Sku	Kurtosis	Kurtosis of the height distribution. $$Sku = \frac{1}{Sq^4}\left[\frac{1}{A}\iint_A z^4(x,y)dxdy\right]$$ Kurtosis qualifies the flatness of the height distribution. Due to the large exponent used, this parameter is very sensitive to the sampling and noise of the measurement.
Spar	Projected Area	Projected surface area.
Sdar	Developed Area	Developed surface area.